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NO. 424

A STUDY OF THE FLOW FIELD INDUCED
BY AN EXPLOSION NEAR THE GROUND (U)

by

J.H.B. Anderson

PCN 21K01

April 1978

Paper presented at the 5th International Symposium on the Military Applications of Blast Simulation, Stockholm, Sweden, 23-26 May 1977.

NOTE: This document reflects the content of the verbal presentation made at the Symposium and represents an updated version of the text printed in the Symposium proceedings.

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ABSTRACT

An experiment is described in which an attempt was made to investigate the phenomenology of an airburst explosion, in particular those phenomena related to the interaction of the blast wave with the ground beneath the charge. The experiment was conducted under free-field conditions using a 493 kg (1086 lb) TNT charge suspended 21.9 metres (72 feet) above the ground. The primary instrumentation was photographic, using shadow techniques to record the trajectories of the shock fronts and smoke puff tracers to record the trajectories of individual air elements entrained in the blast wave.

The analysis of the particle trajectories was based on the technique originally proposed by Dewey. However, the analysis was re-worked to account for cylindrical rather than spherical symmetry, and extended to account for more than one shock wave. Using this analysis, it was possible to completely describe the development of the blast wave in both space and time in the region investigated. Details of the experimental and analytical techniques are given.

The latest results of the analysis of the particle trajectories are presented, and several interesting phenomena are identified related to the reflection of the blast wave from the ground.

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I. INTRODUCTION

1. Over the past several years, considerable effort has been devoted in various research establishments to the documentation of the blast effects from chemical explosions of known characteristics. Considerable theoretical and computational effort has also been directed towards this end, partly in an attempt to reduce the necessity for expensive full-scale experimentation, and partly to extend the data base available from previous experimentation.

2. Much of this work has been devoted to the definition of the blast effects from charges detonated in "free air", i.e., in the absence of boundaries which would obstruct or otherwise affect the propagation of the blast wave. This work also has considerable relevance to the blast resulting from charges placed in direct contact with a reflecting surface, such as the ground, since, to a certain approximation, the blast from such an explosion at a given distance from Ground Zero (the point on the reflecting surface immediately under the charge) is equivalent to the blast at a comparable distance from a charge of twice the yield detonated in free air.

3. It has been known, however, at least since early in World War II that the blast from a given charge at certain distances from Ground Zero can be enhanced by placing the charge at some distance away from the reflecting surface rather than in contact with it, and recent years have seen somewhat of a resurgence of interest in studying the blast effects from such explosions. Quite clearly, the presence of the reflecting surface must result in important changes in the blast wave configuration, and it was the objective

of the investigation described in this paper to attempt a complete description of the phenomenology of such an explosion.

4. Complete details of the experiment described in this paper are given by Anderson (1970, 1974, 1976). The principal investigative technique used was analysis of the particle trajectories, a method which was first proposed by Dewey (1964, 1971). However, for use in the present experiment, the theory had to be extended to account for cylindrical symmetry (as opposed to the spherical symmetry considered by Dewey) and the presence of more than one shock wave. Shadow techniques, using patterned canvas backdrops and ciné cameras, were also used in this experiment to determine the trajectories of the shock waves, but these techniques are well known and, in the interests of space, will not be considered further in this paper.

5. A brief description of the more important experimental techniques is given in Section II. A summary of the theory is included in Section III, while some details of the methods used to reduce the data are given in Section IV. Finally some results from the experiment are presented in Section V.

II. EXPERIMENTAL METHODS

6. The experiment described in this paper was one of a series of twelve carried out at the Defence Research Establishment Suffield in the autumn of 1969. The overall objective of these trials was to measure the blast effects from similar explosive sources as functions of the height of the charge above the surface of the earth. The particular experiment referred to herein was the seventh in the series, for which the charge was suspended 21.9 metres (72 feet) above Ground Zero.

(a) Charge Handling and Support System

7. Since the reflection of the blast wave from the ground was of paramount interest in these experiments, it was required that the charge be suspended in position over Ground Zero rather than supported on a tower,

thereby avoiding any disturbance to the reflection of the blast wave from the surface beneath the charge. It was therefore decided to suspend the charge between two heavy-duty collapsible aluminum towers, each 45.7 metres (150 feet) high, placed 76.2 metres (250 feet) apart with Ground Zero midway between them (Figure 1).

(b) TNT Charges

8. The explosive charges used for most of the events in the series, including the experiment referred to herein, were made from TNT (Trinitrotoluene) and prepared in the manner described by Pennie, Phillips and Holdsworth (1960). The charges weighed about 493 kg (1086 lb) and were 82.5 cm (32.5 inches) in diameter. Detonation was initiated using an electric detonator at the centre of the charge.

(c) Smoke Puffs

9. In order to carry out an analysis of the particle trajectories in the blast wave, the motion of the air had to be made visible, and one of the major developments in this series of trials was means for providing a grid of smoke puffs for this purpose. In previous trials involving study of the particle trajectories, continuous smoke trails were used (Dewey, 1964, 1971) since the blast configuration was such that one-dimensional (i.e., spherically symmetric) flow could be assumed. However, for the present series of trials, the flow was two-dimensional (i.e., cylindrically symmetric), so that continuous trails could not be used.

10. Two proposals were examined. The one involved a mortar which, on being fired, would leave a trail of suitable puffs in its wake (Holsgrove, Klymchuk and Myers, 1971); the other was a small device which could be suspended at the desired point and would produce one puff on being fired (Holsgrove and Klymchuk, 1970). The latter device suffered from the disadvantage that its use would be limited to relatively small-scale trials because of the need to suspend it in position. The use of the mortar, on the other hand, would have been more flexible and would have eliminated the rigging necessary to suspend the static devices. However, development of the mortar concept could not be completed in the time available and therefore the decision was made to use the static device.

11. A highly successful static puff-producing device was subsequently developed during the fall and winter of 1968-69 (Holsgrove and Klymchuk, 1970). Puffs of different colours were tried in an effort to find those which would be best for use with high-speed black-and-white photography when viewed against the natural background (i.e., the sky or the prairie). Eventually, red smoke puffs were used where the sky was the background, and white puffs where the prairie was the background. The complete grid extended 15.2 metres (50 feet) above the surface and 61 metres (200 feet) outwards from Ground Zero, and contained 310 individual puffs.

(d) Stabiliziation of the Ground Surface

12. It was recognized early in the planning of this series of trials that one of the significant variables that would need to be controlled was the state of the surface over which the experiments were carried out. It was, therefore, necessary for the surface of the layout to be made weatherproof and capable of withstanding, to an acceptable degree, the erosive effects of the blast wave. This was to be accomplished, if possible, without changing the nature of the original surface.

13. In order to satisfy these conflicting requirements, it was decided to use soil cement, i.e., to make use of the soil already existing on the layout, but to increase its bearing capacity in order to better resist the pressure loading by the blast wave, and also to increase its elastic strength in order to better resist cratering. Dust control was achieved by spraying the surface with RC-0 cutback asphalt, which also served to seal the surface thereby preventing evaporation of the water necessary to maintain the strength of the soil. Details of the preparation of the surface and the underlying soil can be found in the report by Beare (1970).

III. THEORETICAL BACKGROUND

14. The method used in the analysis of the particle trajectory data in the present experiment was based on the approach first used by Dewey (1964). Dewey's work was limited to the case of one-dimensional spherically-symmetric flows containing only one shock wave, so that use of this method for the analysis of the data from the present experiment required that the theory be

extended to allow the treatment of cylindrically-symmetric flows containing several shock waves. Complete details of this theoretical development are given by Anderson (1976). A brief outline of the method is given below.

15. In principle, if one specifies a point (R,Z) in the vicinity of the detonation and a time T, one has in effect identified an air element. Then, from knowledge of the particle trajectories, one can find the position (and time) at which that air element was first affected by the initial shock wave. This defines the element's initial position, since the air elements can be assumed to be at rest prior to being entrained in the blast wave. The density of the specified air element can then be found by using the equation of continuity in Lagrangian form, which is, for cylindrical symmetry,

$$\frac{\Gamma_0}{\Gamma} = \frac{R}{R_0}\left[\frac{\partial R}{\partial R_0}\frac{\partial Z}{\partial Z_0} - \frac{\partial R}{\partial Z_0}\frac{\partial Z}{\partial R_0}\right]. \qquad (1)$$

Here, (R_0,Z_0) is the initial position of the air element which is found at position (R,Z) at time T, and Γ_0 and Γ are the densities of the specified air element initially and at time T, respectively. For completeness, it is noted that the equations describing the trajectory of the initial shock wave can be denoted by

$$F_0(R_0,Z_0,T_0) = 0 \quad ,$$

where T_0 is the time at which the shock wave passes location (R_0,Z_0).

16. To a very good approximation, all changes in the air element's thermodynamic state after passing through the shock wave can be considered to be reversible and adiabatic. Therefore, definition of the point at which the air element passes through the shock wave also defines its entropy, since this is a unique function of the strength of the shock wave at that point. In addition, using the Rankine-Hugoniot relations, or other more exact relations if desired, the values of the other thermodynamic variables immediately behind the shock wave at this point can be determined. The subsequent change in the density of the air element, as determined using the equation of continuity, can then be used with the isentropic equation of state to determine the changes in all of the other thermodynamic variables.

In particular, for example,

$$\frac{p_I}{\Gamma_I^{\gamma}} = \frac{p}{\Gamma^{\gamma}} \quad ,$$

or

$$\frac{p}{p_0} = \frac{p_I}{p_0}\left(\frac{\Gamma}{\Gamma_0}\right)^{\gamma}\left(\frac{\Gamma_0}{\Gamma_I}\right)^{\gamma} \quad .$$

Here, subscript "I" denotes conditions immediately behind the initial shock wave, while subscript "0" denotes conditions in the undisturbed medium ahead of it.

17. While Equation (1) has general validity, it is nevertheless somewhat difficult t. use when the problem contains more than one shock wave, since the velocity of each air element is in general discontinuous at each shock front. Thus, in the case of two shock waves for example, such as the incident and reflected shock waves in the present problem, it is convenient to rewrite the equation of continuity in the form

$$\frac{\Gamma_0}{\Gamma} = \frac{R}{R_0}\left[\frac{\frac{\partial R}{\partial R_1}\frac{\partial Z}{\partial Z_1} - \frac{\partial R}{\partial Z_1}\frac{\partial Z}{\partial R_1}}{\frac{\partial R_0}{\partial R_1}\frac{\partial Z_0}{\partial Z_1} - \frac{\partial R_0}{\partial Z_1}\frac{\partial Z_0}{\partial R_1}}\right], \tag{2}$$

where (R_1,Z_1) is the point at which the specified air element passes through the reflected shock wave. Again, for completeness, it is noted that the equations describing the trajectory of the reflected shock wave can be denoted by

$$F_1(R_1,Z_1,T_1) = 0 \quad ,$$

where T_1 is the time at which the shock wave passes location (R_1,Z_1).

18. In addition, the scheme outlined above for determining the other thermodynamic variables needs to be modified. These must now be calculated in two steps, since it is necessary to take account of the entropy changes through both the incident and reflected shock waves. Consequently, the state of the specified air element at the point (R_1,Z_1), immediately before being engulfed by the reflected shock wave, is first determined. Then, using

the speed of the reflected shock wave at point (R_1, Z_1) together with the speed of sound and the local particle velocity at this point, the strength of the reflected shock wave at this point may be calculated. This leads to determinations of the values of the thermodynamic variables immediately behind it, after which one can proceed as before. In particular, for example,

$$\frac{p_R}{\Gamma_R^{\gamma}} = \frac{p}{\Gamma^{\gamma}} ,$$

or

$$\frac{p}{p_0} = \frac{p_R}{p_1}\frac{p_1}{p_0}\left(\frac{\Gamma}{\Gamma_0}\right)^{\gamma}\left(\frac{\Gamma_0}{\Gamma_1}\right)^{\gamma}\left(\frac{\Gamma_1}{\Gamma_R}\right)^{\gamma} ,$$

where subscript "R" refers to conditions immediately behind the reflected shock wave, and subscript "1" refers to conditions immediately in front of it.

19. Complete details of the derivation of Equations (1) and (2), as well as of the derivatives contained in them, are given in the reference.

IV. DATA REDUCTION

20. As noted earlier, the motion of the air entrained in the blast wave from the explosion was made visible by using smoke puffs to 'tag' selected air elements, the motions of which were then recorded using a high-speed ciné camera. The position of each smoke puff on each frame was then determined using a film reader facility (Murray and Campbell, 1973). Markers placed in the field of view of the camera were used as references to allow correlation of data obtained from different frames. The "image space" information thus obtained from the film concerning the trajectory of each puff was transformed to "object space" information suitable for further analysis using a modified version of a rectification programme developed by Butler (1966) which was in turn based on an approach outlined by Schmid (1958).

21. The data describing the motion of each air element were thus initially available in the form of coordinate pairs R (horizontal (i.e., radial) distance from Ground Zero) and Z (vertical height above Ground Zero) at discrete times T. However, for further analysis, an analytical description of all of the particle trajectories was required. For this purpose, the data for each

particle trajectory were divided into two segments, one segment corresponding to the flow in the region between the incident and reflected shock waves, and the other segment corresponding to the flow behind the reflected shock wave. This was done since the velocities were discontinuous at each shock front.

22. The data for each air element in the region behind the incident shock wave were then transformed to

$$r = R - R_0 \quad ,$$

$$z = Z - Z_0 \quad ,$$

$$t = T - T_0 \quad ,$$

where R_0, Z_0 and T_0 were as defined in the preceding section. The (r,t) and (z,t) data describing the horizontal and vertical motions, respectively, of each element were then described using functions of the form

$$y = C_1 \tanh\left(\frac{x}{C_2}\right) \quad . \tag{3}$$

23. Evidently, the coefficients C_1 and C_2 in the equations describing a given component of the particle trajectories were not everywhere the same, but were in general functions of R_0 and Z_0. However, behind the incident shock and before the reflected shock entered the picture, the flow was still spherically symmetric, so that it was possible to describe the coefficients C_1 and C_2 as functions of P_0 (equal to $(R_0^2 + (Z - Z_C)^2)^{\frac{1}{2}}$ where Z_C was the height of the charge above Ground Zero) using standard curve-fitting techniques. Only two such curve-fitting operations were necessary since, through use of suitable transformations based on the spherical symmetry of the flow in this region, the corresponding coefficients in the equations describing the two components of a given particle trajectory could be made equivalent.

24. For the region behind the reflected shock, the (R,Z,T) data for each element were transformed to

$$\rho = R - R_1 \quad ,$$

$$\zeta = Z - Z_1 \quad ,$$

$$\tau = T - T_1 \quad ,$$

where R_1, Z_1 and T_1 were as defined previously. The (ρ,τ) and (ζ,τ) data for

each element were then also described using functions of the form of Equation (3). Here, however, the coefficients C_1 and C_2 were functions of R_1 and Z_1, and these could not be combined to form a single independent variable since the flow behind the reflected shock wave was not spherically symmetric. Therefore, surface-fitting techniques had to be used. (A proprietary IBM programme 'SURFIT' was used for this purpose; see references.) Four such surface-fitting operations were necessary, since there were two arbitrary coefficients in the equation describing each of the two components of a given particle trajectory.

25. In this manner, a complete analytical description of all of the particle trajectories was derived, which could be used with the theory outlined in the preceding section to determine the blast parameters at any point in the flow associated with the explosion.

26. While the hyperbolic tangent function chosen to describe the individual particle trajectories (Equation (3)) gave excellent qualitative descriptions thereof, it nevertheless had the unfortunate characteristic that the maximum value of the second derivative, i.e., where the rate of change of the particle velocity was the greatest, occurred at $x > 0$. Moreover, the second derivative of this function was identically zero at $x = 0$, implying that the particle velocity was initially constant. Thus the function chosen was not able to satisfactorily reproduce the initial part of each particle trajectory. Evidently, a function other than Equation (3) could have been chosen to represent the particle trajectories more accurately, but any such function would necessarily have been more complex, leading to a corresponding increase in the complexity of the analysis.

27. Further, it should be noted that the chosen function, Equation (3), could not portray the negative phase of the blast wave, since dy/dx could never become negative. However, except as noted in the next section, the results were in general unaffected by this since the negative phase came into play only at relatively late times. In any event, it would have been difficult to reproduce this phase in an analysis such as the present one which was concerned essentially with gasdynamic phenomena, since the residual gasdynamic effects present at these late times were of the same order as the gravitational and turbulent effects.

28. Equation (3) implied an additional rather important simplification in the particle trajectory analysis, in that the presence of the secondary shock wave from the explosion itself (see, for example, Brode, 1959) was ignored. This was justified on the grounds that (a) the secondary shock wave was weak compared to both the initial shock (the incident shock wave in the present problem) and the reflected shock, and (b) it was so poorly defined in the present experiment as to be largely undetectable in the particle trajectory data. Nevertheless, apart from purely experimental problems, there was nothing in the theoretical approach that would have precluded taking this additional shock wave into account.

V. RESULTS

29. As stated in the introduction, the objective of the investigation reported in this paper was to provide a complete description of the flow field surrounding an airburst explosion. Figures 2 through 7 show some typical results obtained using the particle trajectory analysis described in the preceding sections.

30. The results shown in the figures were obtained by calculating the various quantities of interest at specific times at a number of discrete points in the region surrounding the explosion. Evidently, the description would have been improved by using more points but, nevertheless, some interesting results are revealed.

31. Figures 2, 4 and 6 show vector plots of dynamic pressure at three different times in the evolution of the blast wave. It should be noted that the length of each vector is proportional to the logarithm of the dynamic pressure at the point being considered. This was necessary in order to be able to portray the large range (some five orders of magnitude) of variation of the dynamic pressure in the blast wave. The orientation of each vector indicates the direction of the flow at the corresponding point, and therefore the direction in which the dynamic pressure acts.

32. At early times (Figure 2), the direction of the flow behind the reflected shock is that expected in a blast wave, being, in general, along directions away from Ground Zero and decreasing in speed with increasing time relative to the time of passage of the reflected shock wave. At later times, for example as shown in Figure 6, the flow appears to acquire a uniformly vertical orientation at points some distance above the ground. Closer to the ground surface the particle velocity continues to exhibit a horizontal component which, however, appears to have its maximum not at the ground surface but at a short distance above it. This feature can be related to the static overpressure information shown in Figure 7, and further discussion follows in Paragraph 39.

33. The indication that the flow seems to acquire a uniformly vertical orientation in certain regions is probably realistic up to a point. However, it must be borne in mind that the function used to describe the particle trajectories (see Section IV) was such as to preclude the possibility of portraying flow reversal. It is a matter for speculation, therefore, whether the flow vectors in these regions might not have exhibited a horizontal component towards Ground Zero if a somewhat "better" function had been used to describe the particle trajectories.

34. Figures 3, 5 and 7 show contour plots of static overpressure. Plots of density and temperature could be expected to show similar characteristics.

35. Figures 5 and 7 show the development of a large region of negative overpressure behind the reflected shock wave, resulting from the reflection of the rarefaction wave which follows the incident shock. This region of negative overpressure could be expected to grow in extent as the reflected shock propagates away from Ground Zero. At some point, however, its development would be affected by the presence of the region containing the detonation products from the explosion, but this effect does not extend into the region, either in space or in time, covered by the particle trajectory analysis.

36. The figures also indicate that the maximum negative overpressure increases with time, i.e., the minimum absolute pressure decreases, but there is no indication from these figures concerning what minimum absolute pressure might eventually be attained. However, in Figure 7 it is already somewhat lower than the minimum absolute pressure in the incident blast wave.

37. The figures also show that a region of high pressure persists adjacent to the ground surface. This would appear to result from the reflected shock propagating upward from the ground surface through the region of high pressure behind the incident shock in the period beginning with the incident shock's initial contact with the ground. Although it is not possible to cite specific examples, it is plausible that a similar region of high pressure at the boundary would result from the normal (face-on) reflection of a plane blast wave.

38. As the reflected shock wave propagates away from Ground Zero, the comparatively simple phenomenology shown in Figure 3 becomes modified. A region of high pressure adjacent to the ground surface and centred on Ground Zero continues to persist, with the pressure at the surface decreasing with increasing distance from Ground Zero. Consideration of the well-known results for regular reflection of shock waves confirms that this behaviour is reasonable, since the pressure behind the reflected shock decreases with increasing angle of incidence of the incident shock (except, of course, close to the extreme angle for regular reflection). In addition, a region of high pressure is found behind the reflected shock, the pressures being generally higher close to the ground surface where the reflected shock follows closely behind the incident shock.

39. In between these regions of high pressure, a region of low pressure appears to develop, as shown in Figures 5 and 7. This region appears immediately adjacent to the ground surface and separated by a ridge of higher pressure from the region of low pressure referred to in Paragraphs 35 and 36 above. This ridge of higher pressure can be correlated with the increased horizontal component of the particle velocity above the surface which was identified in Figure 6 and referred to in Paragraph 32 above. Just why the flow field should develop in this fashion is not immediately clear, although it seems reasonable that it should be associated with the changes in the angle of incidence of the incident shock front complicated by the existence of rarefaction waves following the incident and reflected shock fronts and by the fact that the shock fronts are curved.

40. Irrespective of the manner in which this region of low pressure initially develops, Figure 7 shows the far-field pressure distribution beginning to emerge. The region of high pressure adjacent to the ground surface and centred on Ground Zero continues to persist, although decaying with time as it diffuses into the surrounding regions of lower pressure. Likewise, a region of high pressure continues to be found immediately behind the reflected shock front as it propagates away from Ground Zero. In between, a single region of low pressure is found, formed by the amalgamation of the low pressure regions identified in Paragraphs 35 and 39 above. The erosion of the high-pressure ridge between these two regions of low pressure is well illustrated in Figure 7.

41. It should be noted carefully that the results discussed above refer only to the flow field behind the reflected shock: no results have been presented for the flow behind the Mach stem. Since it is the flow behind the Mach stem which governs the pressure on the ground beyond the point where the Mach shock first forms, the results presented above cannot be used to infer the pressure distribution in this region.

42. Unfortunately, it was not possible to study the further development of these features since the calculations at each point were terminated forty milliseconds after the passage of the reflected shock. There were two reasons for doing this. Firstly, as noted earlier, the analysis of the particle trajectories was not capable of accounting for a reversal in the direction of the flow. Any extension of the analysis in a given region to times after the occurrence of flow reversal would, therefore, have given results which were physically meaningless. Secondly, once the particle velocity has reached such low values, other effects such as gravity and diffusion become significant, and these effects cannot be accounted for in the present analysis which is biased towards describing the gasdynamic effects.

43. A complete fluid dynamical description of the phenomena involved is, of course, possible in principle using the experimental techniques described herein. Such a treatment would, perhaps, utilize purely numerical techniques rather than the analytical approach which has been described. However, at very late times after the passage of the shock waves, the motion of the air elements becomes very slow, and the introduction of some kind of smoothing technique into the computations would be necessary in order to remove, say, random

measurement errors. The use of such techniques, however, raises the possibility that details of physical significance might be obscured. The imposition of constraints based on physical reasoning would also be more difficult.

44. In considering the reasons for the appearance of the features in the flow field which were discussed above, one must keep in mind the possibility that at least some of these could be the result of an anomaly in the analytical treatment of the particle trajectories. The analysis of the particle trajectory data is inherently complex and it must be borne in mind that only one such experiment was analysed. Although the possibility of such an anomaly appears to be remote in view of the apparently good analytical description of the particle trajectories which was obtained, nevertheless the ultimate test of the results identified earlier would be to repeat the experiment, perhaps under slightly different conditions.

VI. CONCLUSION

45. Despite certain simplifications which it was necessary to introduce into the analysis of the particle trajectory data, it appears that a reasonably satisfactory portrayal of the explosion phenomena in the present experiment was achieved. Several interesting features of the flow field in the blast wave were identified which could not be completely explained on the basis of available data derived from experiments and calculations using plane shock waves. This would indicate considerable scope for further theoretical and laboratory studies in support of such experiments in the future.

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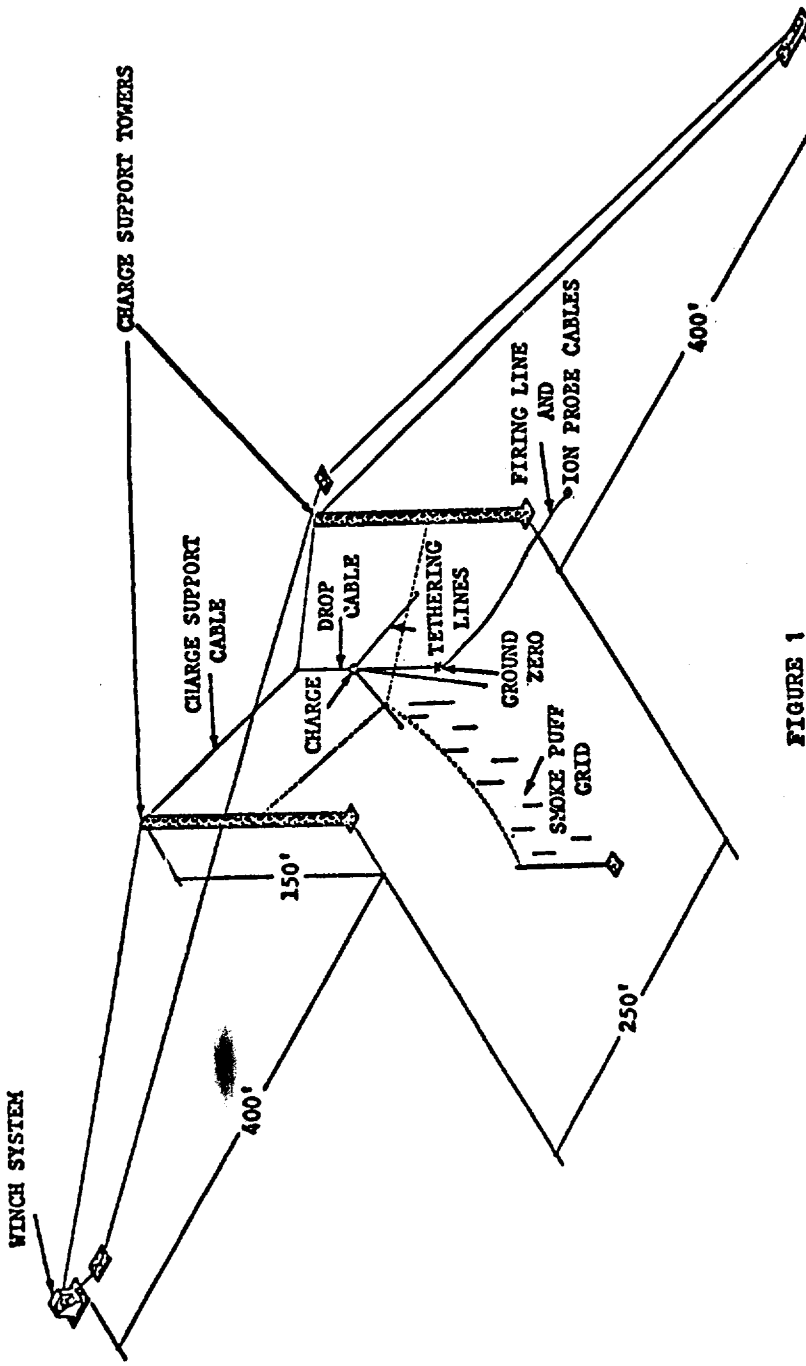

FIGURE 1
DIAGRAM OF CHARGE HANDLING AND SUPPORT SYSTEM
(DETAILS NOT TO SCALE)

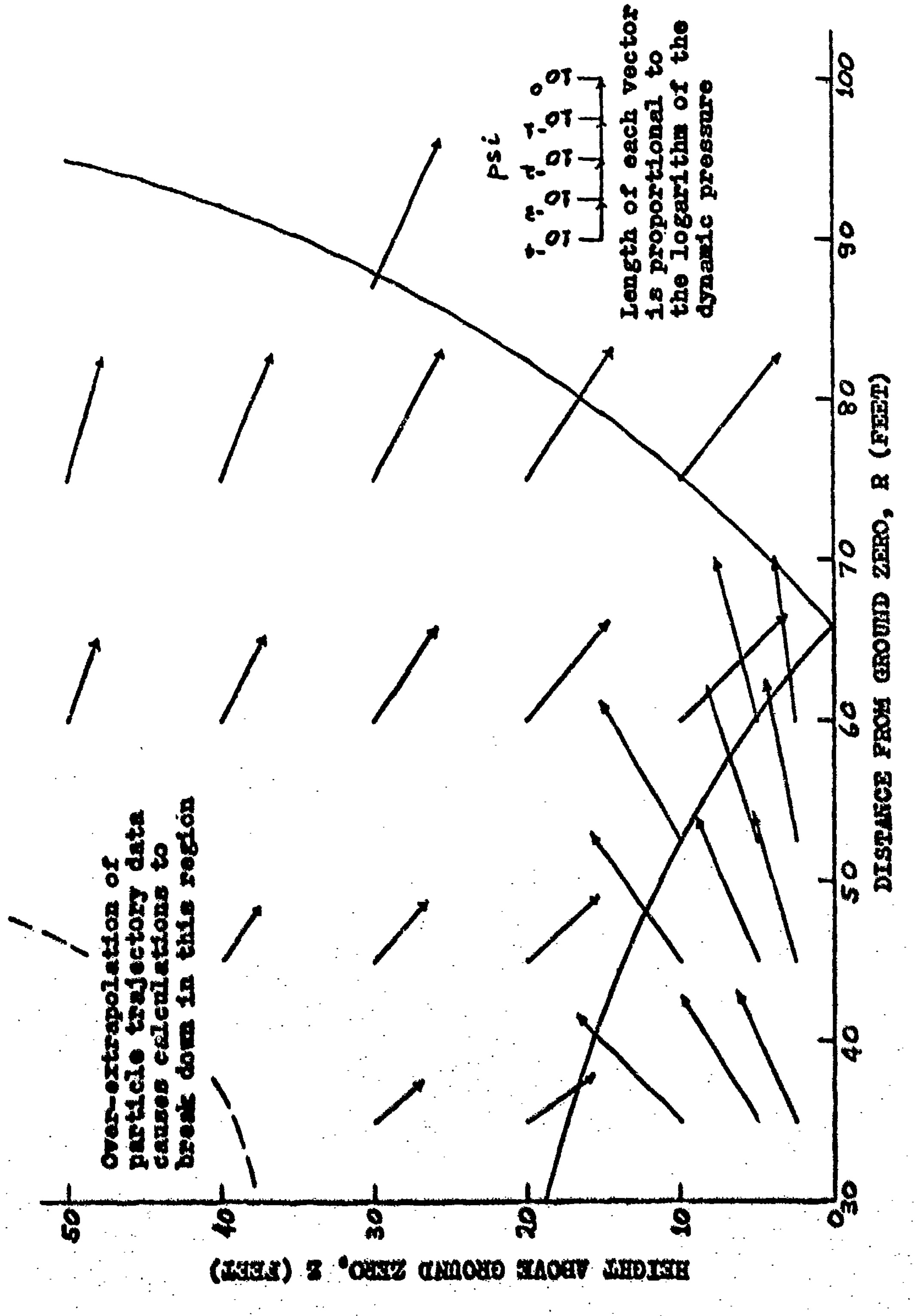

FIGURE 2

VECTOR PLOT OF DYNAMIC PRESSURE DERIVED FROM THE PARTICLE TRAJECTORY ANALYSIS
CHARGE: 1000 LB TNT (NOMINAL); HEIGHT OF BURST: 72.0 FT (NOMINAL)
TIME: ZERO + 44.2 MS

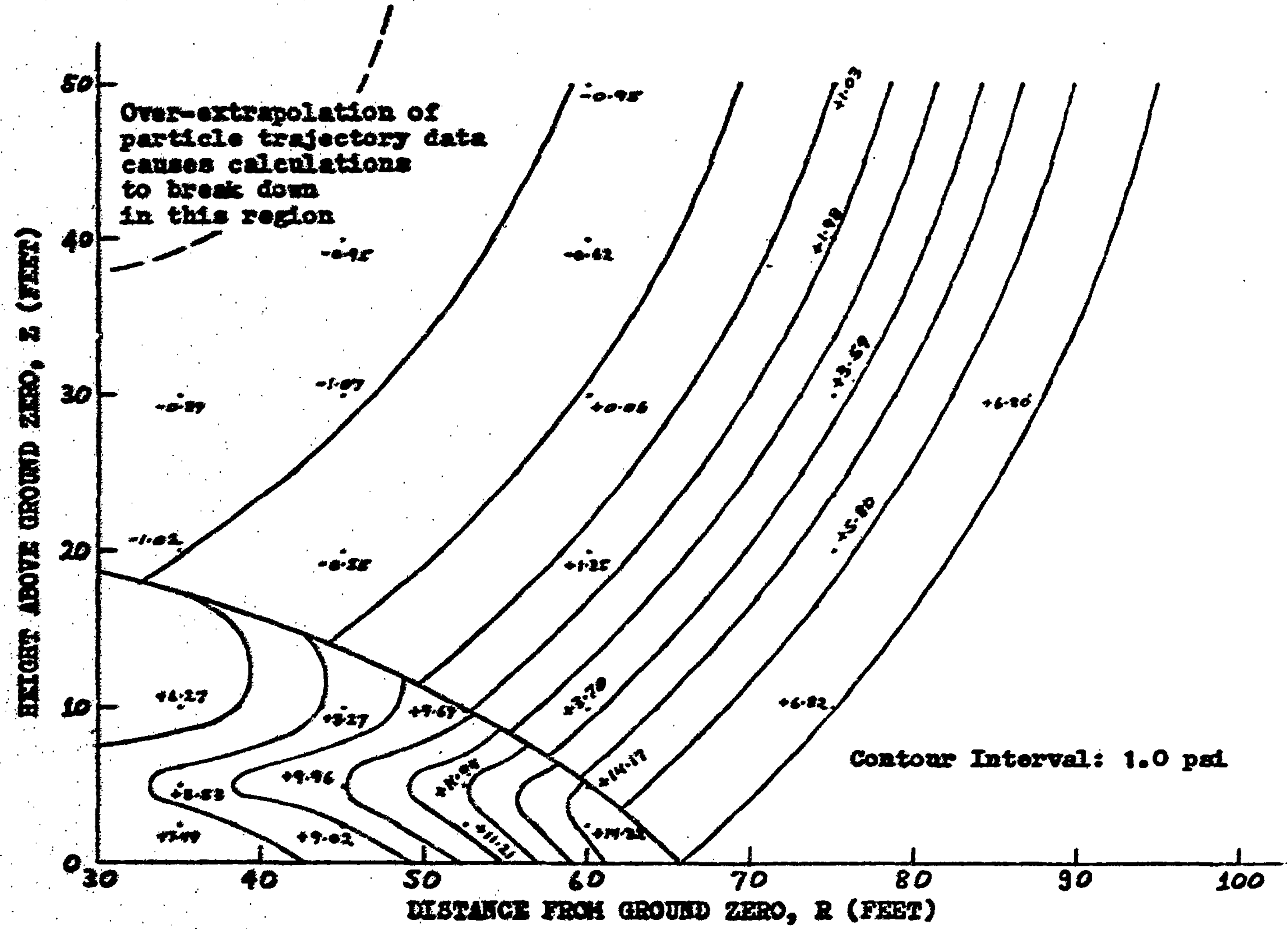

FIGURE 3

CONTOUR PLOT OF STATIC OVERPRESSURE DERIVED FROM THE PARTICLE TRAJECTORY ANALYSIS
CHARGE: 1000 LB TNT (NOMINAL) ; HEIGHT OF BURST: 72.0 FT (NOMINAL)
TIME: ZERO + 44.2 MS

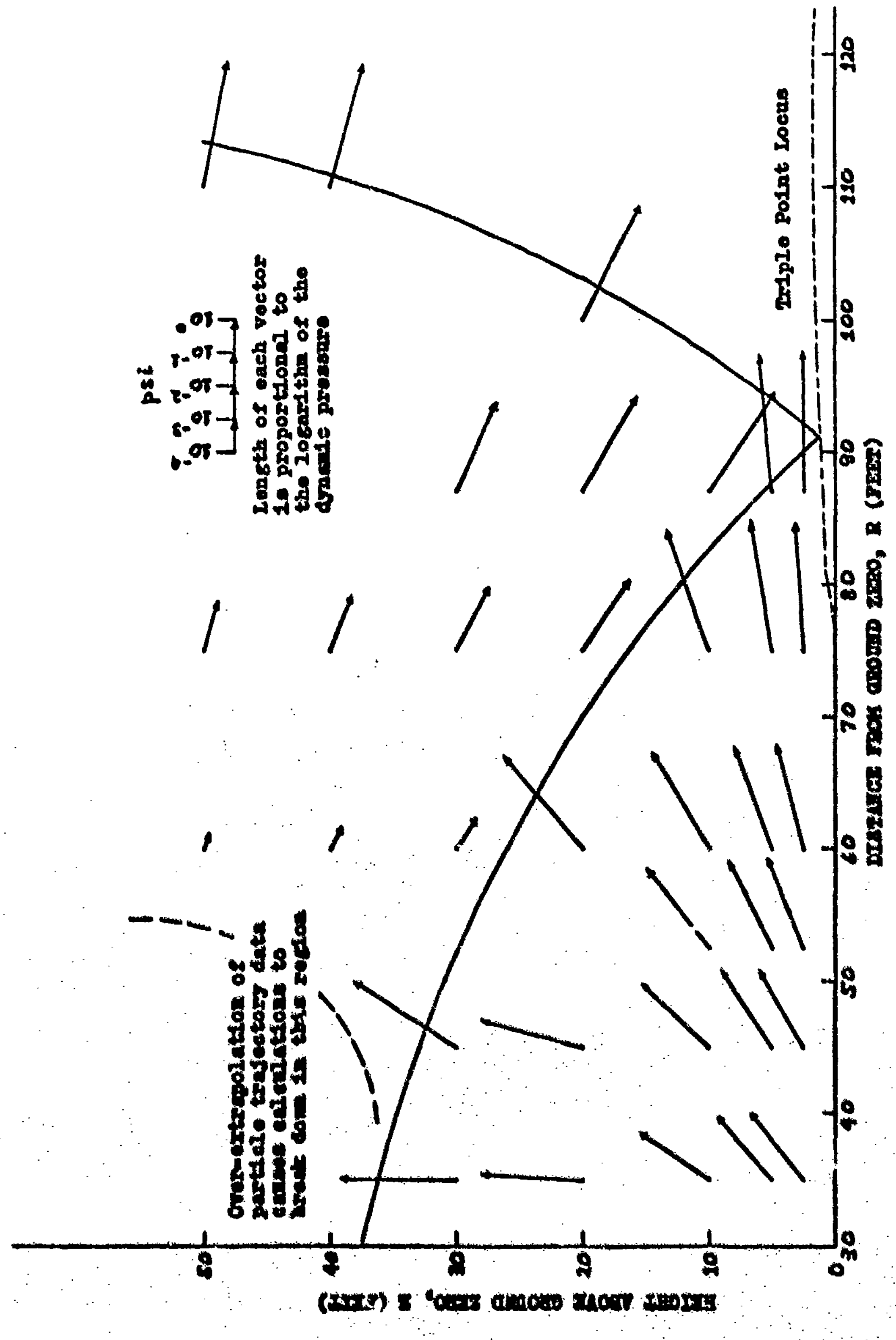

FIGURE 4

VECTOR PLOT OF DYNAMIC PRESSURE DERIVED FROM THE PARTICLE TRAJECTORY ANALYSIS
CHARGE: 1000 LB TNT (NOMINAL); HEIGHT OF BURST: 72.0 FT (NOMINAL)
TIME: ZERO + 57.8 MS

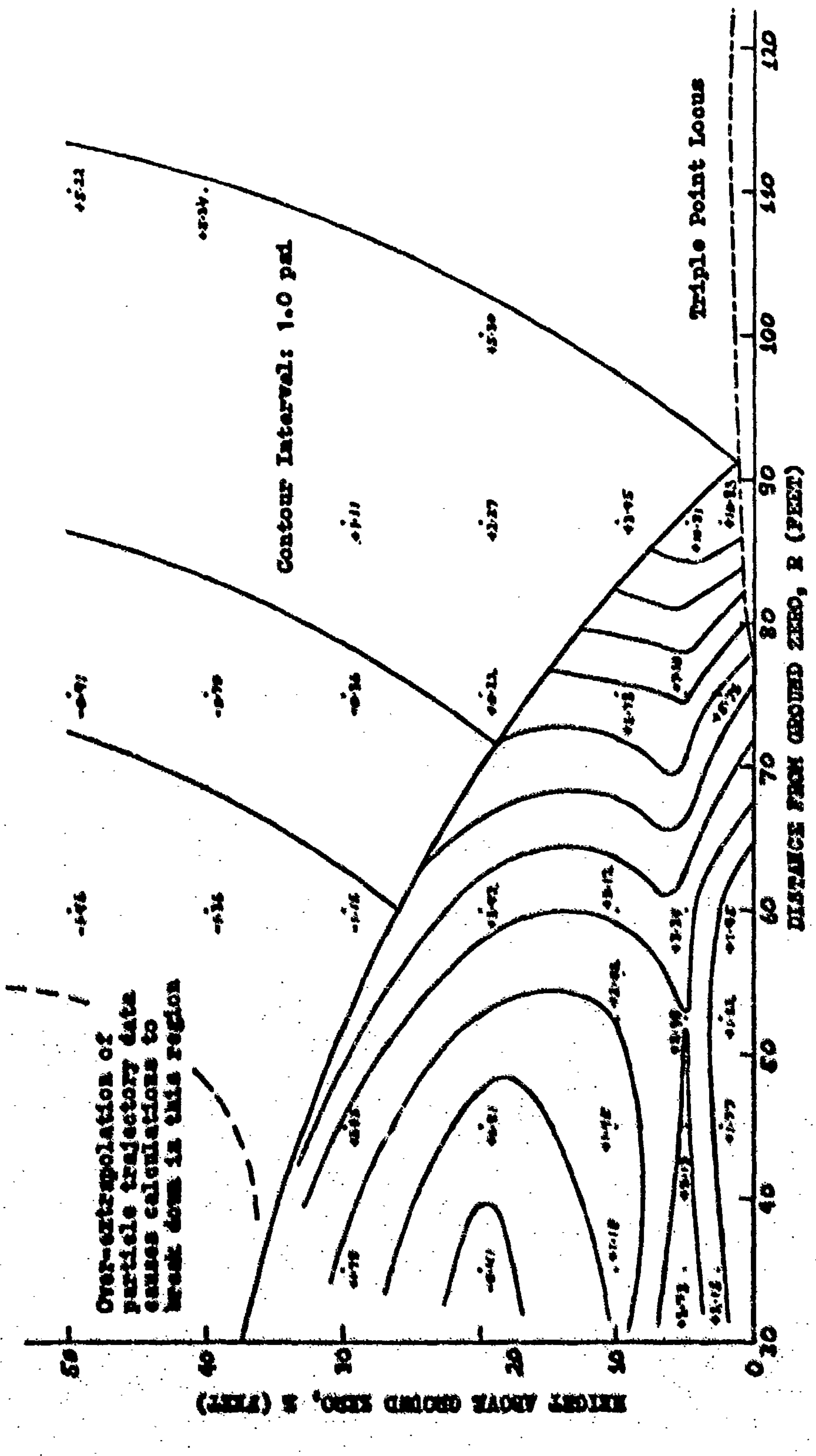

FIGURE 5

CONTOUR PLOT OF STATIC OVERPRESSURE DERIVED FROM THE PARTICLE TRAJECTORY ANALYSIS
CHARGE: 1000 LB TNT (NOMINAL); HEIGHT OF BURST: 72.0 FT (NOMINAL)
TIME: ZERO + 57.8 MS

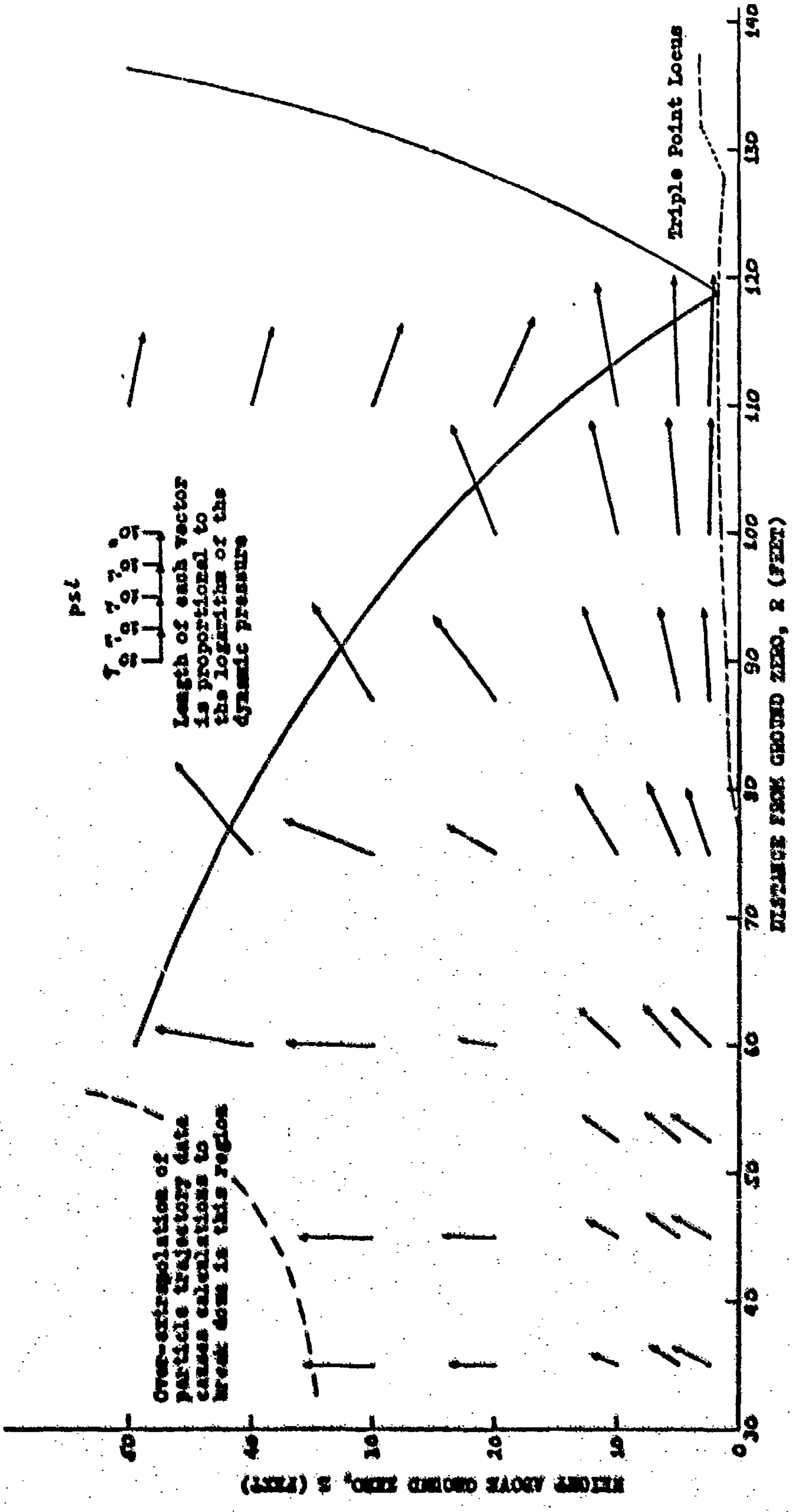

FIGURE 6

VECTOR PLOT OF DYNAMIC PRESSURE DERIVED FROM THE PARTICLE TRAJECTORY ANALYSIS
CHARGE: 1000 LB TNT (NOMINAL); HEIGHT OF BURST: 72.0 FT (NOMINAL)
TIME: ZERO + 75.5 MS

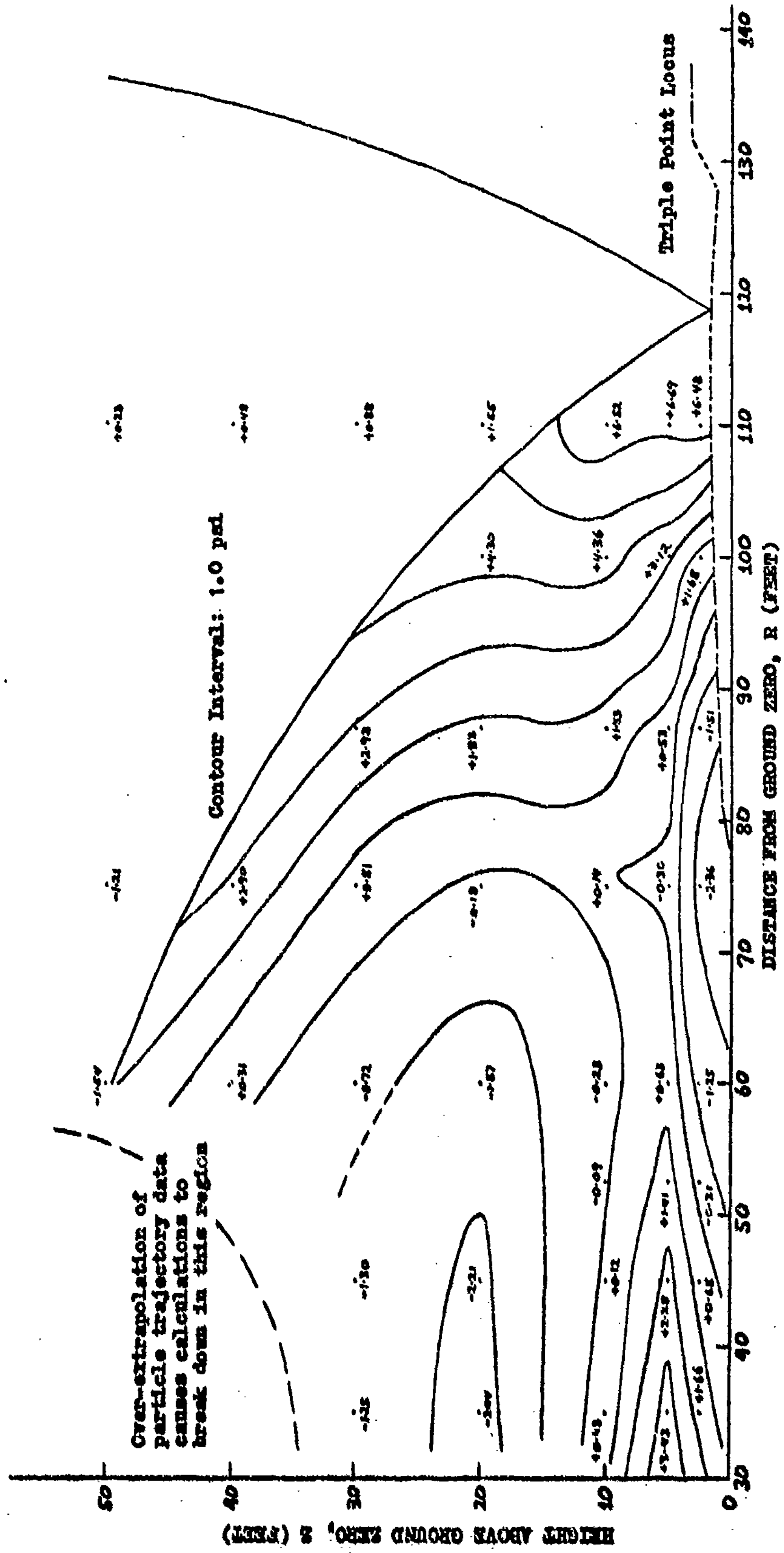

FIGURE 7

CONTOUR PLOT OF STATIC OVERPRESSURE DERIVED FROM THE PARTICLE TRAJECTORY ANALYSIS
CHARGE: 1000 LB TNT (NOMINAL) ; HEIGHT OF BURST: 72.0 FT (NOMINAL)
TIME: ZERO + 75.5 MS

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An experiment is described in which an attempt was made to investigate the phenomenology of an airburst explosion, in particular those phenomena related to the interaction of the blast wave with the ground beneath the charge. The experiment was conducted under free-field conditions using a 493 kg (1086 lb) TNT charge suspended 21.9 metres (72 feet) above the ground. The primary instrumentation was photographic, using shadow techniques to record the trajectories of the shock fronts and smoke puff tracers to record the trajectories of individual air elements entrained in the blast wave.

The analysis of the particle trajectories was based on the technique originally proposed by Dewey. However, the analysis was re-worked to account for cylindrical rather than spherical symmetry, and extended to account for more than one shock wave. Using this analysis, it was possible to completely describe the development of the blast wave in both space and time in the region investigated. Details of the experimental and analytical techniques are given.

The latest results of the analysis of the particle trajectories are presented, and several interesting phenomena are identified related to the reflection of the blast wave from the ground.

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